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Understanding Graininess and Granularity

DEFINITIONS

Graininess — the subjective sensation of a random pattern apparent to a viewer seeing small local density variations in an overall uniform density area.

Granularity — the objective measurement, with a densitometer having a small aperture, of the local density variations that give rise to the sensation of graininess.

rms — root-mean-square. This mathematical term is used to characterize deviations from a mean value. The term standard deviation, which is synonymous, is also used.

Diffuse transmission density — measurement of the attenuation, or reduction, of light transmitted by a photographic image when a collimated beam of light is projected onto the sample and *all* of the transmitted light is collected.

Understanding Graininess and Granularity

This material is intended to give the reader a general understanding of Graininess and Granularity. A slightly more technical discussion of the subject begins on page 15.

The most widely used photographic processes depend upon the light sensitivity of the silver halide crystal. These photographic processes achieve their enormous power to amplify the effects of light by development of individual grains to metallic silver where only a few silver ions have been altered by the light. As a consequence of this image-forming method, a black-and-white photographic image is made up of discrete particles of silver. Even in color processes where the silver is removed after it has served its light-capturing function, the dyes form dye clouds centered on the sites of developed silver grains. It is when the granular structure of the image is enlarged, projected, or otherwise viewed with sufficient magnification that we experience the visual sensation of *graininess.* At low magnifications, the grainy pattern is not seen.

Most photographic materials consist of silver halide crystals dispersed in gelatin and coated in thin layers on a support. The crystals vary in size, shape, and sensitivity, and generally, they are randomly distributed. Within an area of uniform exposure, some of the crystals will be made developable by exposure; others will not. The location of the developable crystals is random. In the photographic process many of the crystals which are exposed by light are reduced to metallic silver by development. Development usually does not change the position of the grain, so the image of a uniformly exposed area of a black-and-white film is a random distribution of opaque silver particles, separated by the transparent gelatin. (Figures 1 and 2.)

The fact that we see a granular pattern does not mean that the eye can resolve the individual silver particles. Such particles range from about 0.002 millimetre down to about a tenth of that size. At normal viewing distance (25 to 35 centimetres), the eye can just distinguish a particle in the order of 0.05-millimetre diameter. Most viewing situations in photography do not involve the 400 times magnification necessary for resolution of an individual particle in the range of 0.001 millimetre in size.

At a viewing enlargement of about 400 times, therefore, we can see directly the graininess due to the individual grains. At magnifications lower than this, for example,

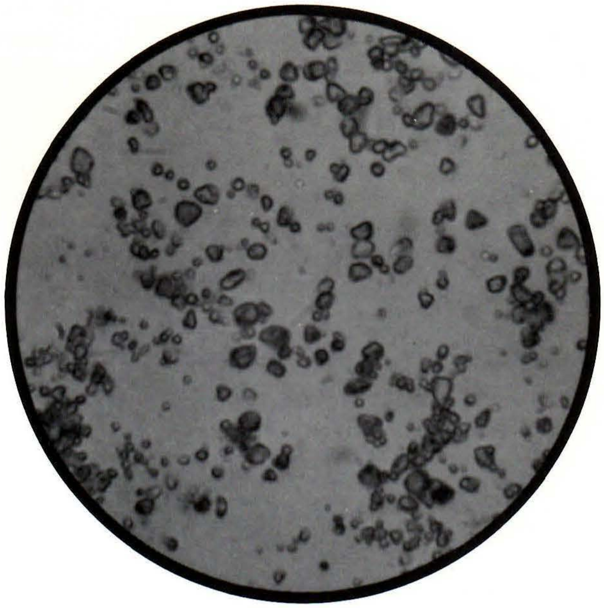

FIGURE 1
Grains of silver halide are randomly distributed in the emulsion when it is made. This photomicrograph of a raw emulsion shows silver halide crystals

FIGURE 2
Silver is developed or clouds of dye formed at the sites occupied by the exposed silver halide. Contrary to widely held opinion, there is little migration or physical joining of individual grains. Compare the distribution of silver particles in this photomicrograph with the undeveloped silver halide in Fig. 1.

20 times, graininess is still apparent. At such magnifications, the eyes do not resolve the individual particles; they do resolve the random groupings of these particles into denser and less dense areas. At still lower magnifications, depending on the graininess of the particular film, the graininess disappears altogether and no granular structure can be detected. (Figure 3.)

Randomness is a necessary condition for the phenomenon. Without randomness, we do not get the sensation of graininess. For example, if many small particles are arranged in a regular pattern, such as that of the halftone dot pattern used in graphic arts, no sensation of graininess is created. When a halftone is viewed at a magnification sufficient for the dots to be resolved, a regular pattern is seen—and is recognized as such. (Figure 4.) At lower magnifications—at which the dots can no longer be resolved—the dot pattern ceases, and only uniform areas are seen.

On the other hand, when a random pattern of small dots is viewed at a magnification such that the ultimate small dots are resolved, no orderly or intelligible image can be recognized. When the magnification is decreased so that the dots cannot be resolved, they appear to blend together to become new units of graininess.

A few spots located, by chance, relatively close to each other appear as a dense unit. Another area which, by chance, has fewer than the average number of opaque spots will be seen as a less dense unit. This process of association of random groupings continues as magnification decreases. The observer progressively associates groups of spots as new units of graininess. The size of these groups gets larger and larger as the magnification decreases, but the amplitude, or the difference in density between the dark and the lighter areas, becomes less and less. Finally, the difference between dark and light groups becomes so small that the observer is not sensitive to it and sees the area as uniform. (Figure 3.)

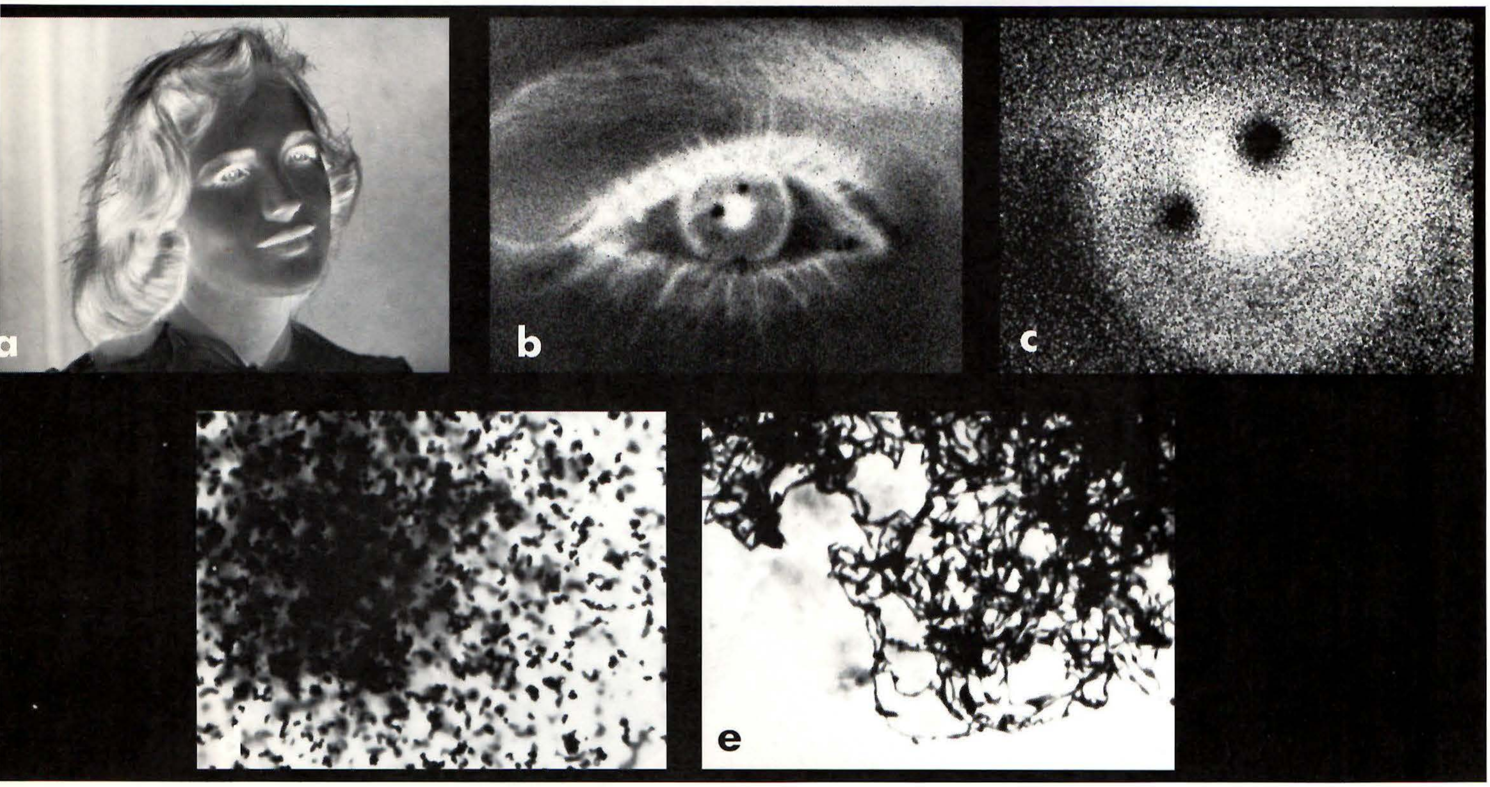

FIGURE 3

(a) *A 2.5X enlargement of a negative shows no apparent graininess.* **(b)** *At 20X some graininess shows.* **(c)** *When a segment of the negative is inspected at 60X, the individual silver grains start to become distinguishable.* **(d)** *With 400X magnification the discrete grains are easily seen. Note that surface grains are in focus while grains deeper in the emulsion are out of focus. The apparent "clumping" of silver grains is actually caused by the overlap of grains at different depths when viewed in two-dimensional projection.* **(e)** *The makeup of individual grains takes different forms. This filamentary silver, enlarged by an electron microscope, appears as a single opaque grain at lower magnification.*

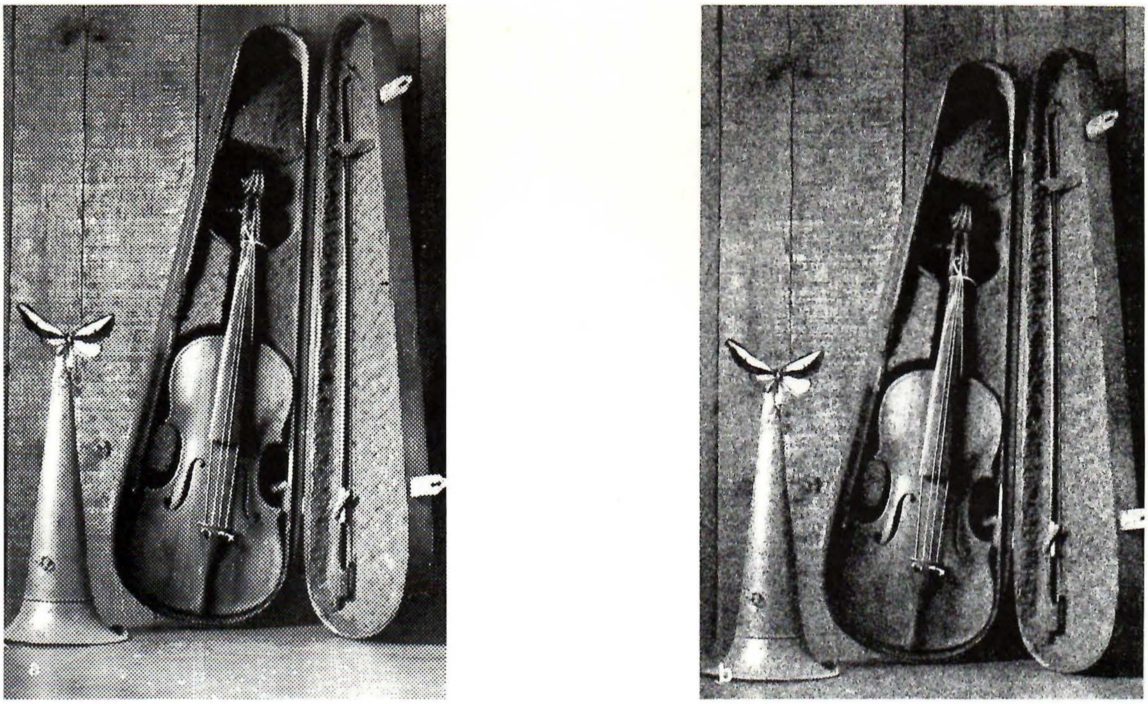

FIGURE 4

If the uniform dot pattern of a conventional halftone is used to reproduce a scene, the eye accepts the image as a smooth, continuous-tone rendition (a). This happens because the dots are regularly spaced. However, when the halftone dots are distributed randomly in an area to reproduce a scene (b) the image looks "grainy." Graininess in the image is due, in part, to the random distribution of the individual elements which make up that image.

Measurement of Granularity

For many years photographic scientists worked with visual methods of evaluating graininess in a quantitative manner. Some were based on the principles of matching a granular pattern with a set of standards. Other methods used "blending magnification," the distance or magnification at which the graininess of a sample disappeared under a particular viewing condition.

The attributes of the photographic image that cause the human visual system to perceive graininess can also be measured and simulated by an electro-optical system. This is the basis of granularity measurement. To provide a numerical value that correlates with the visual impression of graininess, scientists analyze the image structure with a microdensitometer and some statistical tools.

The objective methods now used for measuring granularity rely on mathematical analysis. They depend upon the statistical properties of randomly located particles. The two major advantages of the objective methods are that, by avoiding the use of human observers, instruments can be devised to make rapid and precise measurements and that these values can be manipulated more readily by mathematical means.

Ordinary densitometers measure density over an area that is very large compared with the size of individual silver particles. If the densitometer is used to read several positions on a uniformly exposed and developed photographic material, the density value will be essentially constant. Small variations in the number of particles measured will not affect the reading since there are so many particles in the aperture. When the aperture of the densitometer is reduced in size, however, fewer particles are included and a small change in the number of particles causes the densitometer to show varying values of density. Analysis of the magnitude of these variations of density recorded with the small aperture gives a statistical measure of the granularity of a sample. (See Figures 5 and 6.)

The measuring instrument used to make density samplings of very small regions is a microdensitometer. An aperture for the instrument is selected to give meaningful readings, or values, with the widest range of film samples. Most Kodak films are read with a circular aperture 48 micrometres (0.048 millimetres) in diameter. The measurement actually derived from the microdensitometer

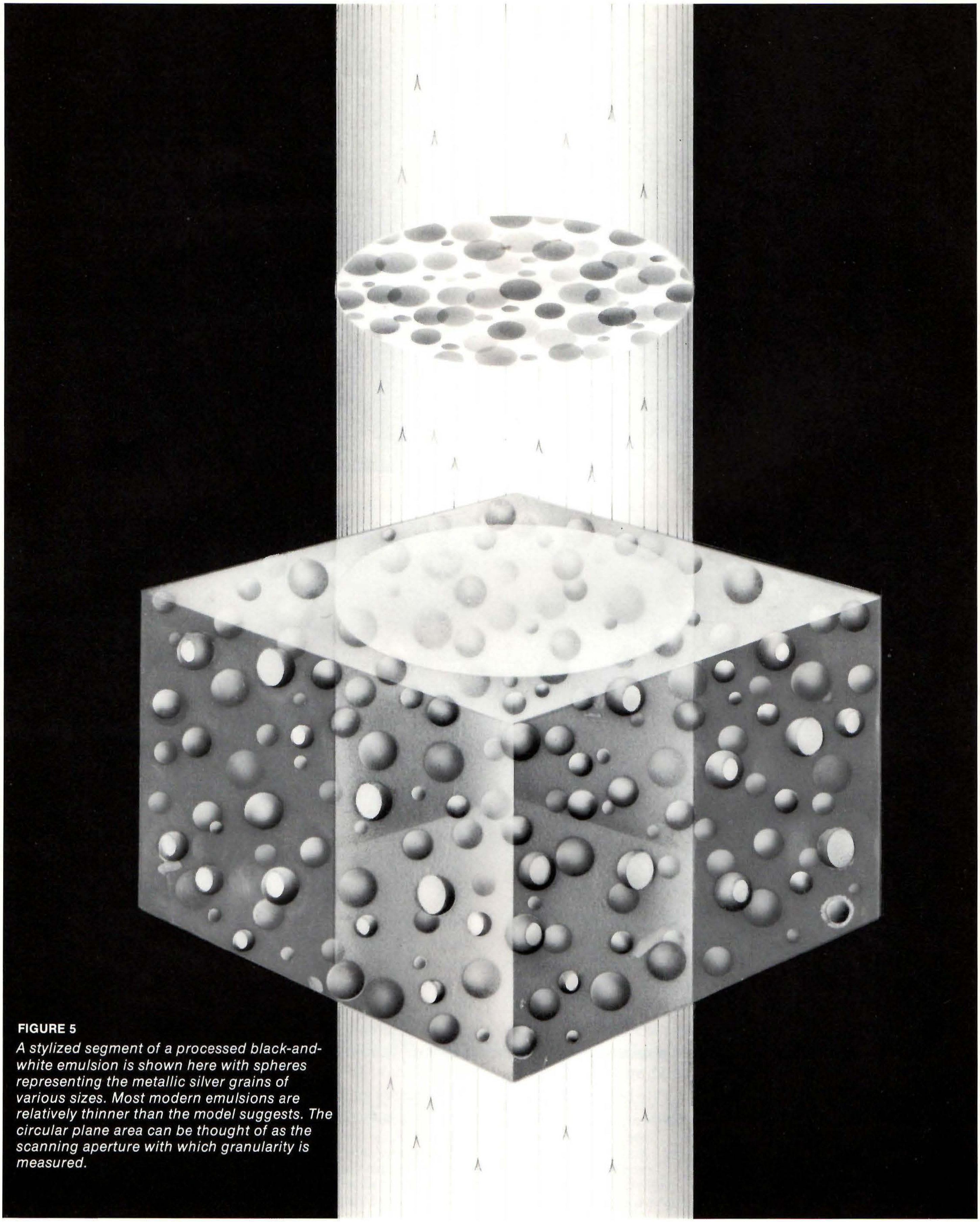

FIGURE 5

A stylized segment of a processed black-and-white emulsion is shown here with spheres representing the metallic silver grains of various sizes. Most modern emulsions are relatively thinner than the model suggests. The circular plane area can be thought of as the scanning aperture with which granularity is measured.

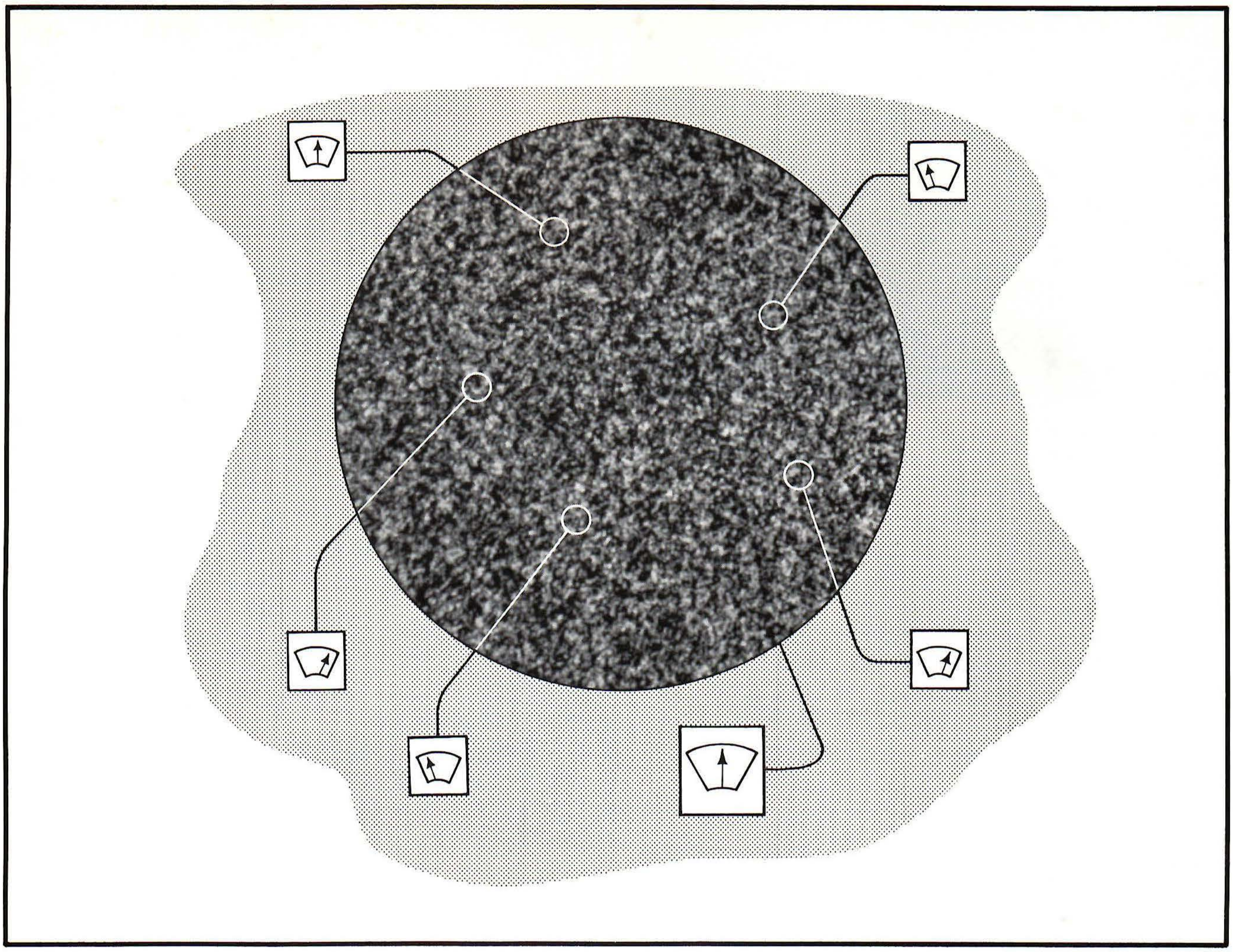

FIGURE 6
A large aperture "sees" a vast number of individual silver grains. Therefore, small local fluctuations have practically no effect on the density it records. Small apertures (about one-twentieth of the large aperture diameter) detect random differences in grain distribution when they sample the large "uniform" area.

sampling is dependent on the size of the aperture.

With granularity measurements of uniformly exposed and processed silver halide emulsions, there is an approximate correlation between granularity values obtained with a given size scanning aperture and the apparent graininess seen at a given viewing magnification. Higher magnification makes the sample look more grainy. Correspondingly, a higher value for granularity is recorded when the sample is measured with a smaller aperture.

In practice, the instrument is not used to sample discrete areas, nor does the operator take individual readings for calculation. Instead, an area of *apparently uniform* density is continuously scanned by the aperture. The transmitted light is imaged on a photosensitive pickup, and the current produced is then fed (through suitable electronic circuitry) to a meter which is calibrated to read the standard deviation of the random density fluctuations. (See Figure 7.)

Standard deviation is a statistician's term used to describe the variations of a group of samples about their average. In this case, it is used to describe the variations in density found when the grainy material is scanned with a small aperture. The quantity derived by this analysis correlates very well with the subjective observation, graininess. A term now generally used to designate the quantity is root-mean-square (rms) granularity; standard deviation and root-mean-square of the variations are actually different terms for the same quantity.

When the standard deviation of density, or rms granularity, is recorded (using the usual Kodak method for measurement), it is a small decimal number. For ease in comparing numbers, the standard deviation is multiplied by a factor of 1,000. This yields a small whole number, typically between 5 and 50.

A microdensitometer measures only a very small spot on a photographic material, and the mechanism of projecting and collecting a light beam in the instrument pro-

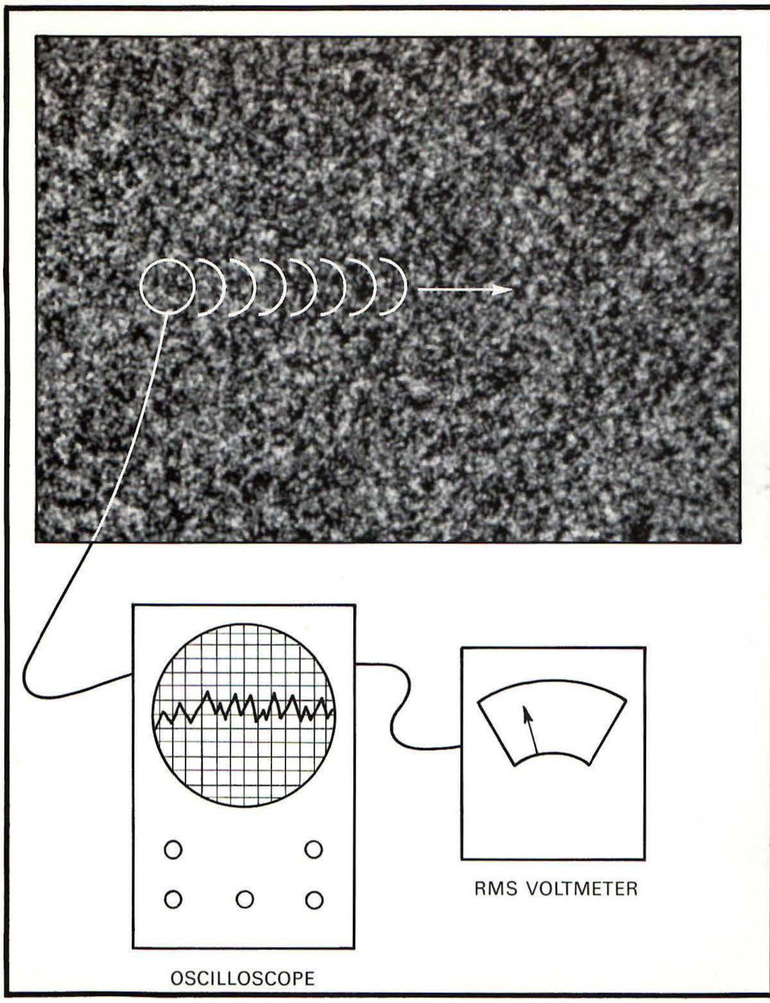

FIGURE 7
The signal from a continuous density-scan of a grainy emulsion appears the same as random electrical noise when displayed on an oscilloscope. The rms voltmeter gives a direct readout of "noise level."

duces semi-specular, rather than diffuse, light. This gives rise to a density reading in a microscopic area different from that recorded with a standard diffuse densitometer. Therefore, a correction is introduced in the granularity measurement so that it will correlate with diffuse density readings. So, we have added the term *diffuse* in reporting rms granularity values. The value for *diffuse rms granularity* of a film may differ slightly from the value previously reported for *rms granularity*. This is a result of the change in instrument calibration and reading.

The rms granularity instrument used at Kodak is calibrated to measure American National Standard diffuse visual density (PH2.19-1976). The granularity values for Kodak black-and-white and color negative films are determined at a *net* density of 1.00, while the values for reversal and direct duplicating films, both black-and-white and color, are determined at a *gross* density of 1.00.

Kodak publishes, in various instances, both granularity values and descriptions called graininess classifications or adjectives. These classifications are used to describe, subjectively, the appearance of graininess when using a wide range of Kodak films in a variety of situations. While these adjectives can be related to the objective measures of granularity, no single relationship holds for all usage conditions with all films.

Graininess Classification
Microfine (MF)
Extremely Fine (EF)
Very Fine (VF)
Fine (F)
Medium (M)
Moderately Coarse (MC)
Coarse (C)
Very Coarse (VC)

Because these classifications are based directly on granularity measurements, they might more properly be called "granularity classifications," but because graininess is a term more familiar to practicing photographers, the term graininess is used.

There is not always a direct correlation between the graininess classification of a film and the appearance of graininess of the final image. Some of the practical factors that affect graininess are covered in a later section. However, experience has shown that there is quite good correlation between the ratings of like materials. For example, black-and-white general-purpose films rated "extremely fine" will show less graininess when enlarged than those rated "very fine," when the conditions of negative density, amount of detail, contrast, and magnification are the same.

However, the correlation does not hold when films of different types are being compared because of the differences in their uses. For example, while a color transparency film and a color negative film may measure to produce the same graininess classification, such as extremely fine, the act of enlarging the color negative film to make a color print involves a considerable increase in contrast, since the contrast of color negative films is relatively low. Thus the appearance of graininess in the print is enhanced. On the other hand, the contrast of the transparency is already high, so that enlarging it on paper, either directly on a color reversal paper or via an internegative onto a color negative paper, actually reduces the print contrast, which tends to minimize the apparent graininess. Projecting a transparency either produces the same contrast or reduces it, depending on the projector optical system, screen surface, and ambient light conditions.

Two points should be made about graininess. The values of granularity measurements were assigned classification names some years ago when the graininess levels of most Kodak films were higher. As many of the films have been improved, their classifications have been lowered; they are actually finer grained than before. As a result, the graininess classifications of the commonly used films now cluster in the fine, very fine, and extremely fine categories. The second point is that graininess is a characteristic of films, not prints. It is generally only seen, however, in prints made from greatly enlarged film negatives.

An illustration in matrix form has been prepared using

FILM GRAININESS MATRIX
KODAK 1979-80 35mm Films

FIGURE 8

This illustration, in matrix form, shows a range of graininess of 35 mm films as seen in enlarged prints made at various magnifications. A discussion of how the illustration was made, and why the graininess of different types of films that have the same graininess classification appears to differ, can be found in the text.

a number of popular Kodak 35 mm films to illustrate the effects of a range of graininess as seen in prints made at various magnifications (Figure 8). A general concept of the graininess of films, as printed, can be gained by studying the illustration. The methods used in preparing the matrix are discussed in a later section.

Factors That Affect Graininess

As indicated in the section entitled "Some Practical Effects of Graininess," other factors besides the film affect the graininess.

Different developers and different amounts of development affect the graininess of black-and-white films, as does the amount of exposure that determines the densities of various areas of negatives.

With color films, the processes are rigidly fixed, although push processing of KODAK EKTACHROME Films is sometimes done to increase the film speed. Hence, the effect of development on color films is rarely a factor in their graininess, although push processing increases the graininess.

In color negative films, however, exposure affects graininess in an opposite manner. KODAK VERICOLOR and KODACOLOR Films are made with emulsion layers of two graininess levels. Increasing the exposure (up to a point) places more of the density in the finer grained layers, which actually reduces the graininess of the images as the densities are increased.

Classification of KODAK Films

The graininess classifications apply to the complete range of films manufactured by Kodak. No attempt is made to have separate classifications for films used for different special purposes, such as amateur, professional, aerial, motion picture, or microfilming. The films in one particular category usually do not utilize the entire range of classifications from very coarse to microfine. The films for one type of usage, for example, might be covered completely by the terms fine, very fine, and extremely fine, while another group might have films classified as medium, moderately coarse, and coarse.

Granularity and Color Materials

It is generally recognized that most color materials do, indeed, exhibit a grain structure. This is due to the formation of the dye image from the original silver halide grains. Even though a complicated sequence of chemical reactions is initiated by the reduction of these silver halide crystals to produce dye images, the necessary conditions for graininess are usually not disturbed. That is, the fundamental small units of the colored dye image are numerous and randomly distributed. So graininess persists.

After the color-forming process is complete, the silver is removed. The dye usually forms semitransparent clouds with centers at the silver sites. The clouds become less dense, and then disappear, a short distance from the central sites. In practice, these dye clouds vary in size, uniformity, transparency, and density distribution. They do, however, give rise to a sensation of graininess just as that we perceive in black-and-white materials. So also, we can measure the granularity of color materials and assign a granularity value. When we make these measurements, however, we must be sure that the microdensitometer sees the color films as the eye sees them.

One might expect that a photographic image made up of cyan, magenta, and yellow dye particles would appear more grainy than the corresponding silver image because of color contrast. In fact, the eye does not distinguish color in very small detail close to the resolution limit of the eye. It sees only brightness differences. Graininess of color materials, at least at the threshold limit, depends primarily upon the luminosity contribution of the separate dye layers.

When color films are enlarged or projected, the dye-cloud clusters act in a manner similar to silver grain clusters in black-and-white films, and at high magnifications cause the appearance of graininess in enlarged color prints or on the projected screen image.

The illustration of cyan layer dye clouds (Figure 10) shows how the dye clouds are formed around the developing silver grains and how the dye clouds visually associate into clumps when there are several development centers close to each other. The illustration also shows how the size of the dye-clouds can be reduced by the use of competing couplers—which lowers the graininess of the images.

Some Practical Effects of Graininess

With the trend to smaller and smaller film formats has come the need for greater and greater enlargement. This is true both for prints from negatives and for projected movies or transparencies. With this requirement for great enlargement has come a renewed awareness of the granular structure of films.

The photographer wants a fine-grain film, but not at the expense of sensitivity, or film speed. Unfortunately, faster films usually have larger grains. In a fast film with large silver halide crystals, these crystals have a greater probability of being made developable. The larger silver halide crystals normally develop to larger particles of metallic silver. The selection of a film is usually a compromise between available speed and tolerable grain.

The pursuit of more favorable speed-grain ratios is a constant concern of photographic researchers. The relationship of emulsion speed to the grain structure is of practical concern to the photographer. It is of vital importance to the scientist who uses photography. The speed-grain relationship indicates whether or not the photographic material will detect radiation and, if it is detected, whether or not it will form an image that can be recognized.

Graininess and granularity depend primarily upon the grain size, or the range of grain sizes, built into the film by the manufacturer. However, the effective graininess of most black-and-white negative films is significantly increased by overexposure (and subsequent normal development), by extended development, or by the use of highly active, high-contrast developers. So to get a fine-grain negative, one must start with a film having inherently fine grain. Normal development of a fine-grain film will yield a more satisfactory negative than the attempt to modify the grain structure of a comparatively coarse-grain film with a special-purpose, solvent developer. While the graininess of the coarse-grain film may be reduced with the solvent developer, this is usually at the expense of film speed and image sharpness.

Developers formulated to yield moderate contrast with normal development times and having low-to-medium activity will preserve the inherent grain characteristics of a film without suppressing film speed. High-energy developers which produce high contrast can significantly increase the granularity of a film. So also will the granularity increase with overdevelopment, which increases contrast.

Printing a negative usually increases the appearance of graininess in the image, even though the granularity of the positive material is usually fine enough so that the material does not contribute to the print graininess. The granularity of the enlarged negative is amplified by the contrast of the print paper or film, which is nearly always

FIGURE 9

The differences of grain in segments of three prints made from a fine, a medium, and a coarse-grain negative are evident in these enlargements.

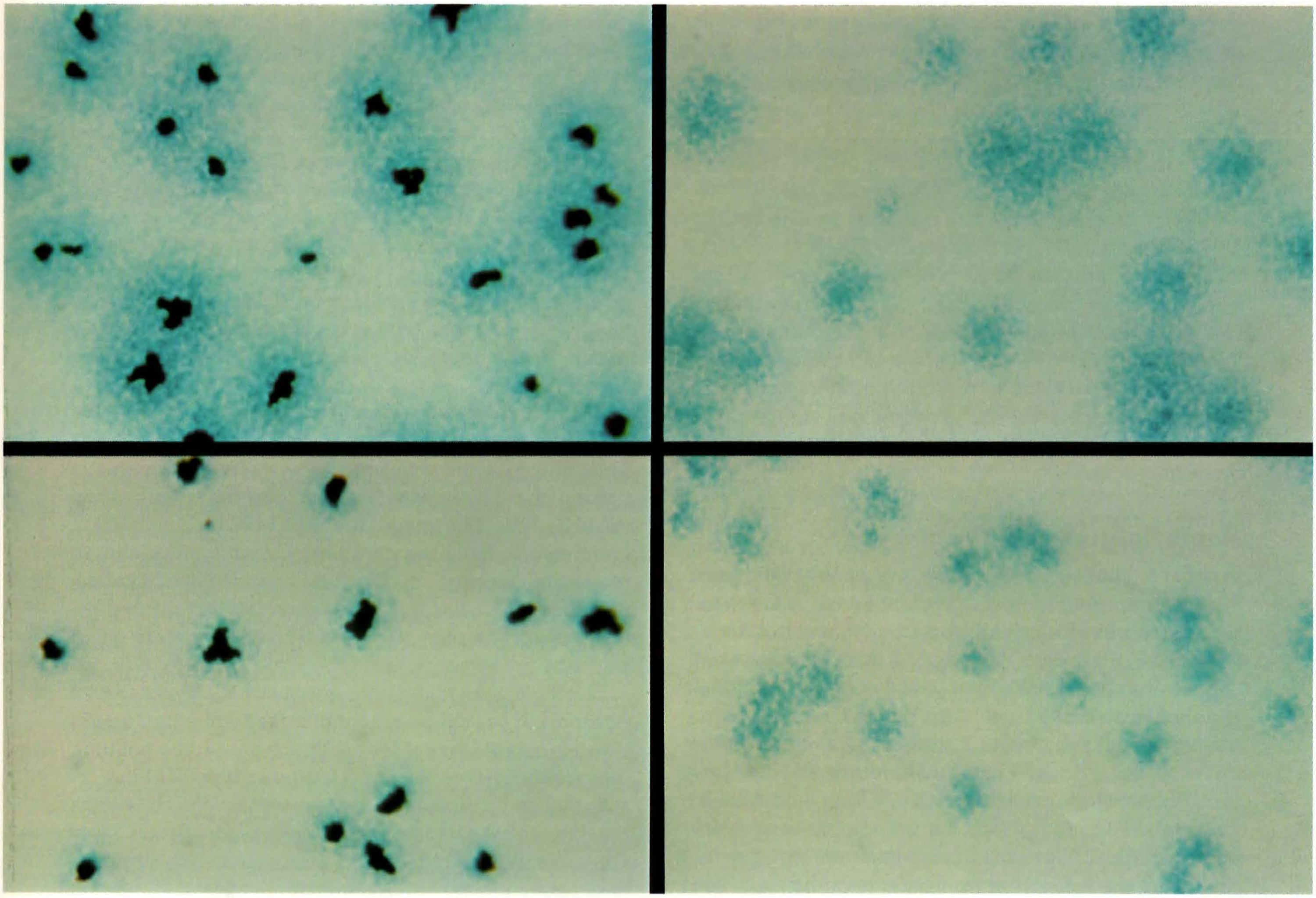

FIGURE 10

The above illustrations are 1200X photomicrographs of a special cyan color film layer with incorporated coupler made very thin to permit showing the structure. The upper left picture is the film after color development, and shows the metallic silver grains surrounded by dye clouds. The upper right picture shows another area of the same film after bleaching and fixing.

The lower two pictures show the same type of film developed with a color developer containing a competing coupler, which reduces the size of the dye clouds; hence, reduces the graininess. Some Kodak color film developers contain competing couplers to make the color images finer grained.

greater than one. It is this amplification factor that makes it difficult to predict directly the graininess that will be perceived in the print from a negative of a given graininess rating. The combination of the negative graininess plus the contrast amplification makes the negative contribution to print graininess usually dominant over the contribution of the positive material.

The degree of sharpness of the printing operation also affects how much of the negative grain is reproduced in the print. While it is possible to reduce print graininess by unsharp printing, the inevitable loss of image sharpness makes this an undesirable solution with most photographic subjects.

Graininess is most evident in the midtones of a print. The light tones of the print are on the toe of the print material characteristic curve. The slope of the curve is very much lower than unity, hence the contrast with which the graininess is reproduced is very low—decreasing its visibility.

In the dark tones, the eye is not able to distinguish the graininess as well. The eye can easily detect density differences as low as 0.02 when the average reflection density is about 0.10 (typical print highlight density), but can only detect density differences of the order of 0.20 when the average reflection density is 1.80 to 2.00 (typical print dark-tone density).

In the midtones, the print material contrast is at a maximum, and the eye can readily distinguish small density differences; therefore, the graininess is greatest.

Another factor in the appearance of graininess is the amount of detail in an area. Large areas with fairly uniform densities permit graininess to be seen easily, while the graininess is much less evident in areas full of fine detail.

The preceding discussion generally holds for transparency prints to be projected as well as for reflection (paper) prints. However, since in the case of transparency prints the viewing is by enlarged projection, the granularity of

the print film may also contribute to the graininess of the projected image. It is more difficult to predict the magnification at which projected print images will be viewed since, besides the projection magnification, there is the additional variable of the viewing distance from the observer to the screen. Both of these factors affect the picture magnification, and thus the graininess.

When a motion-picture film is seen at great magnification (as from a front-row theater seat), the viewer may be aware of graininess in the form of "boiling" in the image. The sensation, which is caused by the frame-to-frame change of grain position, is one of grains "crawling" or "boiling" all over the uniform areas of the image. Graininess is most noticeable in projected motion pictures, or projected transparencies, at a critical density level. The critical diffuse density is about 0.9 for color and 0.6 for black-and-white.

Matrix Illustration of Graininess

In order to convey a comparison impression of the graininess of a number of Kodak films, a series of tests were run, the results of which are shown on the matrix illustration (Fig. 8) on the fold-out pages. Five different magnifications are shown horizontally, while the different films are shown vertically.

Space limitations make it impossible to illustrate the entire range of Kodak films, so a selection of commonly used 35 mm films was made. KODAK Technical Pan Film 2415 is shown along with the commonly used black-and-white films. This film is a very thin emulsion film that can be developed to produce very low-grain negatives of extremely high resolving power (more than 300 lines/mm). It is becoming popular with photographers for the production of high-quality, greatly enlarged images from 35 mm negatives. With this film the limits to image definition are nearly always determined by the camera optics rather than the film.

The color transparency films shown give a graininess comparison between slow and fast films, and between KODACHROME and EKTACHROME Films of the same speed. Tungsten films and KODAK EKTACHROME 200 Film (Daylight) are not shown. The graininess of the 200 speed film is between that of the 64 speed and 400 speed EKTACHROME Films shown. Graininess of the EKTACHROME Films and EKTACHROME Professional Films of the equivalent speed is the same.

The graininess of KODACOLOR II Film, KODAK VERICOLOR II Professional Film, Type S, and KODACOLOR 400 Films are compared. All films shown are those being manufactured by Eastman Kodak Company in late 1979, except for KODACOLOR 400 Film. A change in emulsion on this film has just been made, and the new emulsion is becoming available as this is written. Both the old and the new emulsions are shown.

Because of the high degree of enlargement required of 35 mm images, the matrix was limited to 35 mm films. Where there are roll films with the same product name, the graininess can be expected to be essentially the same.

The subject was chosen to have an even tone area without detail, while other areas with considerable detail were included. A face was included to show the effects of graininess on a readily recognizable subject. The continuous tone area was divided into a gray and blue area to illustrate what happens in color films when less than the three layers make a major contribution to the density level. The gray and blue tones were chosen to closely match in the reproductions on black-and-white panchromatic films.

Each film was exposed at five calculated distances so that the print image would be the same size at 1X, 4X, 8X, 16X, and 32X magnifications. For example, the image size on the 1X images is about one inch high, while the size of the 32X images is about 1/32 inch high. Care was taken to have the densities of each type of film be reasonably consistent. Black-and-white films were all developed to have the same contrast and printed on the same grade paper, while the color films were given standard processing.

The films were taken right out of stock with no special selection. It should be recognized that while the images shown are real (except for the effects caused by halftone reproduction) they do not necessarily represent the results that might be obtained where some of the conditions are different. A reasonable print color balance match was aimed for, but a slight variation was accepted to minimize the cost.

The halftone reproduction is as close to the originals as we could make it. The photographic original, however, could be examined with a magnifier. Magnification of the halftone reproduction only reveals the halftone dots.

In the illustrations of the higher magnifications, the graininess appears worse than it would in a large print. At 32X magnification, the whole print would be about 30 x 45 inches—the illustration has only about 1/1000 of the area of the whole print. You will view the illustration at about 14 inches—whereas the entire print would be normally viewed at about 60 inches to obtain true perspective. If, however, a very small section of a film is enlarged to make a small print, the graininess appears similar to that shown in the large magnification columns. Aside from the halftone influence and this viewing distance effect, the illustration gives as fair a comparison of the graininess of the selected films as we could achieve in a single test.

The black-and-white films were developed in small, stainless-steel tanks at 20°C (68°F) with agitation at 30-second intervals. The developers and times were as follows:

KODAK Film	*KODAK Developer*	*Time*
Technical Pan 2415	MICRODOL-X (1:5)	7 min.
PANATOMIC-X	MICRODOL-X (1:3)	7 min.
PLUS-X Pan	D-76 (1:1)	6 min.
TRI-X Pan	D-76 (1:1)	9 min.
Recording Pan Film 2475 (ESTAR-AH Base)	DK-50 (Undiluted)	5 min.

All prints were enlarged with a semi-specular condenser enlarger. The transparencies were enlarged to size on KODAK VERICOLOR Internegative Film 6011 and contact-printed on KODAK EKTACOLOR Paper. The color negatives were enlarged directly on EKTACOLOR Paper.

Limits of Sharpness

With faster films, the limiting factor on image sharpness is usually the film. The illustrations in this test show that with the finest grain films, the limit of sharpness has become the camera lens. The loss in sharpness that shows in the 32X enlargement of KODAK Technical Pan Film, for example, is caused by the lens—not the film. The section of film enlarged to make this image was about 0.70 x 1.05 mm (0.027 x 0.041 inches)—only a tiny section of the 24 x 36 mm (0.945 x 1.420-inch) frame.

The lens used to make these images was a high-quality 24 mm wide angle lens. This was made necessary by the wide range of image sizes required and the limited studio space available. As it was, the lens-to-subject distance was 21.6 metres (70 feet 8 inches) for the smallest image.

In practice, since the 32X prints represent only about 1/1000 of the entire 30 x 45-inch print, the degree of sharpness shown in the 32X samples would generally be considered satisfactory in such a large print.

With the coarser grain films, the limit of sharpness is the film and not the lens.

The slower films, such as KODAK Technical Pan Film 2415, were exposed with the lens at wide apertures in order to get the correct exposure. This decreased the sharpness of the image. It is noticeable in the 32X print of this film—where the grain is invisible, but the image sharpness is limited.

The color transparency films have been included in the matrix because prints are often made from transparencies. Comparisons of the appearance of graininess made from color negatives and transparencies can be considered, along with other factors, in the selection of a type of film. Commonly, however, 35 mm transparencies, or slides, are projected, and the factors that pertain to projected images discussed earlier apply to the image graininess seen on the projection screen.

*On the basis of the Central Limit Theorem of statistics, it can be assumed that if all possible measurements are made on a uniformly exposed and developed sample, the distribution of these measurements will be approximately Gaussian.

A Touch of Science

For the technically inclined, the following discussion gives a more detailed explanation of the actual development of granularity measurement.

One can describe a characteristic of randomly occurring events by a normal distribution (Gaussian) curve.* This normal distribution is a symmetrical, bell-shaped curve starting from a very low value, increasing through a maximum, and decreasing to a very low value again. If one locates a mean value in this distribution, one can describe any member of this family of curves by the standard deviation (σ). For example, the illustration shows three normal distribution curves. They have the same general form but differ in their spread. If a value of standard deviation (σ) is defined as the distance from the mean which includes 68 percent of the area under the curve, it is obvious that the broader curve would require a large value σ to meet this requirement and the more peaked curve would require a small value of σ. Yet, because of the general form of this distribution curve, the value σ (together with the mean) will determine any particular member of this family of curves.

As we have said, the granularity of a photographic material is determined by measuring random deviations of density recorded when a uniformly exposed and developed sample is scanned with a very small circular aperture (in the order of 50 micrometres in diameter). With the measurement of a sufficiently large number of these values (a thousand or more) the distribution of density values becomes approximately normal, or Gaussian, about the mean when the density levels are near those specified for granularity measurement. Since the normal distribution curves (with a specified mean) differ

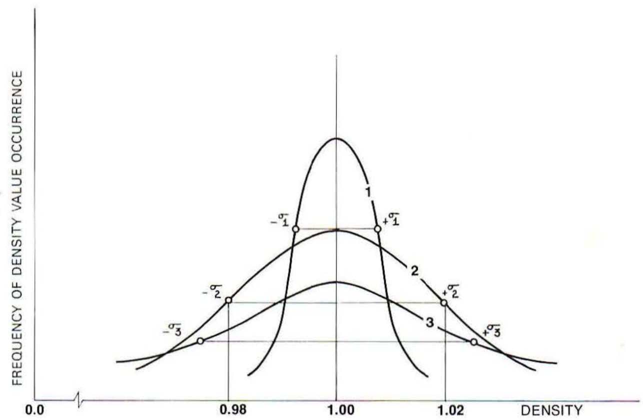

FIGURE 11

Low (σ_1), medium (σ_2), and high (σ_3) granularity values are represented by these normal distribution curves. All three curves have the same mean—the uniform, large-aperture density of 1.0.

in their spread, the standard deviation specifies the curve. The standard deviation of density, designated σ (D), is the square root of the mean of the squares (root-mean-square) of the individual deviations. It is the standard deviation, σ (D), that we measure and, multiplied by 1000, designate as diffuse rms granularity.

When an acceptable sample is scanned for granularity, the microdensitometer converts the sample's random transmittance variations to random current variations by means of a light-sensitive device, such as a photomultiplier tube. The output signal of the phototube appears the same as random electronic noise. When the signal is corrected for the phototube's own inherent noise, the remaining noise-like signal can be attributed completely to the random variations in the sample. It can be shown that the standard deviation of the current variations is approximately proportional to the standard deviation in sample density and thus rms granularity. Because the instrument density actually measured results from semi-specular light transmittance through the sample in the microdensitometer, a further correction is introduced in the final readout to produce a value for *diffuse rms granularity* (see the illustrations on pages 7 and 8).

Values for diffuse rms granularity derived as described above can be compared to determine the granularity relationships of different photographic materials (in specified processes). However, this comparison should be made only when the scanning apertures are identical. If the size of the scanning aperture is changed, the value for the granularity of that sample also changes. When the value of diffuse rms granularity [σ (D)] is given, the diameter of the scanning aperture must also be specified to describe the granularity characteristics of a sample.

For black-and-white films uniformly exposed to light, the product of σ (D) and the diameter of the scanning aperture is approximately constant for the sample under examination. This relationship was developed by E. W. H. Selwyn in 1935. For the relationship to hold, the distribution of the grains in the emulsion must be random, and the size of the grains must be small in relation to the size of the aperture.

Several types of photographic materials do not obey the Selwyn relationship. Among these are color materials, photographic prints made from negatives, and radiographs, all of which are intended for direct viewing. Since the granularity values obtained for these materials with various apertures cannot be interchanged, some criterion for selecting the scanning aperture must be used. Stultz and Zweig proposed a relationship between the diameter of the scanning aperture and the viewing magnification. Based on that relationship, they developed an approximately corresponding series of apertures and viewing magnifications.

As noted previously, the aperture routinely used for reporting granularity values for Kodak materials is 48 micrometres. This aperture is chosen for routine granularity measurements because it is useful for a large range of photographic materials. For very special materials, such as some microfilms or high resolution plates, a granularity value generated with 6- and 12-micrometre apertures may also be reported.

As we have seen, the basis for reporting granularity of photographic materials is the reduction of data to a single value which correlates with the visual impression of graininess at one fixed density. This is the number reported by Kodak as *diffuse rms granularity*. More complex analyses of the grain structure have been derived. These are autocorrelation and power-spectrum (Wiener-spectrum) analysis. While these complex measurements are not routinely reported, they are useful where the transfer of information by photographic materials is studied—either in a printing system or as part of an electro-optical interface.

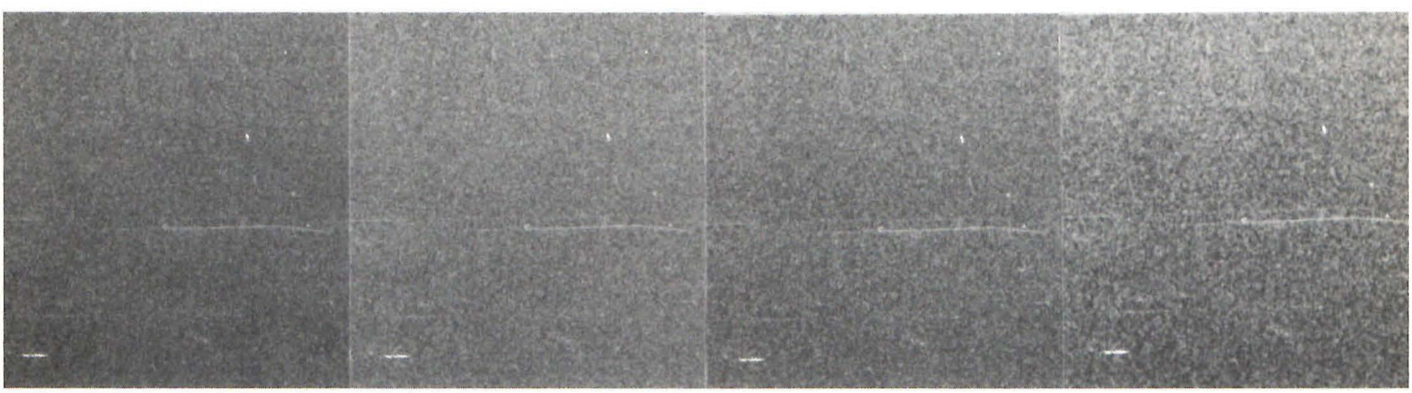

FIGURE 12

The above illustrations were made from 10X enlargements of a uniform area of a TRI-X Pan negative. A condenser enlarger was used. The prints were made on KODAK POLYCONTRAST Rapid II RC Paper; the sections were printed with KODAK POLYCONTRAST Filters PC-1, PC-2, PC-3, and PC-4, from left to right. The differences in graininess are entirely due to the differences in print contrast.

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New in This Edition:

- Matrix illustration showing the graininess in prints made from twelve Kodak black-and-white and color films at magnifications up to 32X.
- 1200X photomicrographs showing the dye clouds that form color film images.
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- Discussion of the affect of the contrast grades of printing papers on graininess.
- Explanation of why films of different types (transparency, b/w and color negative) may have the same graininess classification, but may exhibit different levels of graininess when printed.

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E-77, KODAK Color Films
F-5, KODAK Professional Black-and-White Films
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